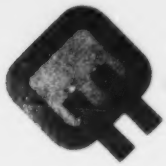

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A NUMERICAL MODEL FOR DIAGNOSING SURFACE WIND AND TEMPERATURE FIELDS SUITABLE FOR PSOD's APPLICATIONS

Report No 86-270-K

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ABSTRACT

A one-level, sigma-coordinate numerical model for computing surface winds and temperatures under the mesoscale influences of orography, friction and heating or cooling has been developed and implemented onto the Meteorology Section's computer system. Simulations of 12 hours consecutively on February 6, 1986 and the corresponding predictions by the CMC spectral model are presented. It is suggested that the model is able to produce quantitatively reasonable surface winds and the variation of surface temperatures.

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EXECUTIVE SUMMARY

A NUMERICAL MODEL FOR DIAGNOSING SURFACE WIND AND TEMPERATURE FIELDS SUITABLE FOR PSOD's APPLICATIONS

Y.T. Tam
K.H. Schaedlich

This report describes a numerical mesoscale model suitable for diagnosing surface wind and temperature fields for Power System Operations Division's applications. The model is a modified version of the Research Division, one-level, sigma coordinate wind field model which calculates surface winds and temperatures using horizontal momentum and temperature tendency equations and includes terrain effects, surface friction and diabatic heating or cooling.

The model was constructed using "segment programming," in order to reduce the computer requirement. The input meteorological data required to generate the forecast are obtained from the real-time, upper-air data available from the Canadian Meteorological Centre of Atmospheric Environment Services.

The model has been applied to simulate surface winds and temperatures for the Lakeview region. In general, the model simulated winds agree quantitatively with the AES CMC-predicted values. However, there are differences between the magnitude of the model simulated and CMC-predicted surface temperatures. Recommendations of possible improvements to the surface temperature calculation are given.

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A NUMERICAL MODEL FOR DIAGNOSING SURFACE WIND AND TEMPERATURE FIELDS SUITABLE FOR PSOD's APPLICATIONS

1.0 INTRODUCTION

1.1 Background

The need for predicting surface winds and temperatures has been recognized for various specific applications within Ontario Hydro. Typical examples are the study of air pollutant dispersion, planning of nuclear emergency scenarios and determination of water levels of lakes and rivers for hydro-electric power production. To accomplish this need, the Meteorology Section of Power Systems Operations Division (PSOD) has initiated a project to (1) create a forecasting weather data base and (2) develop a diagnostic technique so that surface winds and temperatures over a limited area of interest can be generated.

At present, the principal source of forecasting weather data is the predicted output of the Canadian Meteorological Centre's (CMC) operational spectral and finite-element models. These models are synoptic-scale models which have a horizontal grid network covering the entire northern hemisphere with a grid size of 381 km. The model output is updated twice daily from the 0000 and 1200 GMT analyses. Obviously, both the spatial and temporal resolutions of these models are not capable of producing detailed mesoscale and microscale effects that may influence or even dominate local weather.

These mesoscale and microscale effects include physical features of the area of interest such as surface terrains and land-lake interfaces and also diurnal features of differential heating. Due to the computer requirement, it is not practical to modify the CMC spectral or finite-element model to resolve the above-mentioned effects. However, it is possible to apply a diagnostic, limited-area, numerical model to produce wind and temperature fields when given synoptic-scale conditions. In other words, the diagnostic model could be applied to the output of the CMC models and generate winds and temperatures of greater detail.

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In the literature, there are two types of such diagnostic models: the mass conservation type models, such as Sherman (1978) and the primitive equation type models, such as Keyser and Anthes (1977), Danard (1977) and Mass and Dempsey (1985).

The Environmental Science Section of Research Division has developed a surface wind field model that is of the second type and is an adaptation of the model of Danard (1977). The model calculates surface winds and temperatures using horizontal momentum and temperature tendency equations in sigma coordinates ($\sigma = \frac{p}{p_s}$) and includes terrain effects, surface friction and diabatic heating or cooling. The model has been previously applied for the Lakeview, Nanticoke and Pickering areas using historic synoptic observations as input information and the results were reasonably realistic. Accordingly, the model was chosen for the present project.

1.2 Scope of the Present Study

The major objectives of the present study were to

(1) implement the wind field model onto Meteorology Section's computer system,

(2) simplify the input file so that the model can be applied to the output of the CMC operational spectral or finite-element model,

(3) optimize the computer code for execution time and storage requirement, and

(4) verify the model simulations.

Though the surface wind field model has been tested and documented, for completeness, it will be briefly described in Section 2.0. Section 3.0 presents the modifications to the model to meet the objectives of this study.

The model will be used by operational weather forecasters at the Meteorology Section to generate meteorological information needed for routine and specific applications. A detailed user's guide to the model is given in the Appendix. An experimental case is discussed in Section 4.0. It is followed, in Section 5.0, by a discussion and conclusions.

2.0 MODEL DESCRIPTION

2.1 Model Formulation

The model integrates equations for the winds and temperatures at the surface level ($\sigma = 1$ in sigma coordinates). The wind is calculated from the horizontal momentum equation given as

$$\frac{\partial \vec{V}_s}{\partial t} = -\vec{V}_s \cdot \nabla \vec{V}_s - (g\nabla Z_s + RT_s \nabla \ln P_s) - f\vec{k} \times \vec{V}_s + \vec{F} + K_M \nabla^2 \vec{V}_s \ , \qquad (2\text{-}1)$$

where $\vec{V}$, T and P are the wind vector, temperature and pressure, respectively. The subscript s denotes surface values. t is the time, g is the acceleration of gravity, Z_s is the terrain height above mean-sea-level, R is the gas constant, f is the Coriolis parameter, $\vec{k}$ is the vertical unit vector, $\vec{F}$ is the frictional force, K_M is the horizontal momentum eddy diffusivity and ∇ is the horizontal gradient operator. As seen from Equation (2-1), the surface wind vector at any grid location is determined by the balance of horizontal advection, pressure gradient force, Coriolis acceleration, frictional drag and diffusion. The terrain effects are included in the pressure gradient term (the second term on the right-hand side of Equation (2-1), in parentheses).

The surface temperature is calculated from a tendency equation derived from the first law of thermodynamics

$$\frac{\partial \theta_s}{\partial t} = -\vec{V}_s \cdot \nabla \theta_s + K_T \nabla^2 \theta_s + Q \ , \qquad (2\text{-}2)$$

where θ is the potential temperature, K_T is the horizontal thermal eddy diffusivity and Q is the diabatic rate of surface heating or cooling. Equation (2-2) indicates that the temperature at any grid location on the surface is determined by horizontal advection, diffusion and diabatic heating or cooling. The influence of terrain effects on temperature is presented in the advection term (the first term on the right-hand side of the equation).

The surface pressure is determined by a pressure tendency equation which combines the hydrostatic equation with the perfect gas law

$$\frac{\partial \ln P_s}{\partial t} = -\frac{g}{RT_s \theta_s} \int_0^H \frac{\partial \theta}{\partial t} \, dZ \ . \qquad (2\text{-}3)$$

Here, H is the thermal boundary layer height and Z is the height above surface. It should be noted that Equation (2-3) is derived by assuming that the pressure field is affected by the underlying surface only to a height H above the surface. A relationship of

$$\frac{\partial \theta}{\partial t} = \frac{\partial \theta_s}{\partial t} \left[\frac{H - Z}{H}\right] \qquad (2\text{-}4)$$

is used in the present model to link the θ and θ_s .

The magnitude of Q is obtained by

$$Q = \frac{\theta_s}{T_s} \frac{\Delta T}{\tau} , \qquad (2\text{-}5)$$

where ΔT is the difference between the actual final surface temperature T_f (observed or forecasted) and the pseudo-initial surface temperature T_i obtained by linear extrapolation downward from 700 and 850 mb, ie,

$$\Delta T = T_f - T_i . \qquad (2\text{-}6)$$

$\Delta T > 0$ refers to heating and $\Delta T < 0$ refers to cooling. τ is the time interval over which the heating or cooling takes place. In other words, the surface heating or cooling Q will change the surface temperature by an amount of ΔT within time τ.

For heating cases, H is calculated from a formula

$$H = \frac{\Delta T}{\gamma_d - \gamma} , \qquad (2\text{-}7)$$

where γ_d and γ are dry adiabatic lapse rate and the free atmosphere lapse rate, respectively. For cooling cases, H is calculated from an equation given by Laikhtman (1961) and Hanna (1969)

$$H = 0.75\ V_g\ [\frac{g}{T_s} \frac{\Delta\theta}{H}]^{-1/2} , \qquad (2\text{-}8)$$

where V_g is the geostrophic wind at the surface and $\Delta\theta$ is the increase in θ from surface to H. $\Delta\theta$ is given by

$$\Delta\theta = \frac{\theta}{T}[-\Delta T + H(\gamma_d - \gamma)] . \qquad (2\text{-}9)$$

The magnitude of the frictional force is determined from an empirical formula given by Deardorff (1972)

$$\vec{F} = \sqrt{2}\ c\ C_D\ V_s^2\ h^{-1} , \qquad (2\text{-}10)$$

where c is a stability constant with values of 2.8 for stable and neutral atmospheric conditions and 1.0 for extremely unstable conditions. C_D is the drag coefficient given as

$$C_D = 1.0 \times 10^{-2} \qquad (2\text{-}11)$$

over land, and

$$C_D = 1.1 \times 10^{-3} + 5.6 \times 10^{-5} V_g \qquad (2\text{-}12)$$

over water in the present model.

h is the momentum boundary layer height and is determined from

$$h = H \quad \text{for } \Delta T < 0 \qquad (2\text{-}13)$$

and $$h = H + H_L \text{ for } \Delta T \geq 0 \ , \qquad (2\text{-}14)$$

where H_L is the thermal boundary layer height calculated from Equation (2-8) for $\Delta T = 0$.

2.2 Method of Solution

2.2.1 Numerical Scheme

The study domain is divided into a grid network. In the present study, the domain contains 20 x 20 grid points with an equal spacing of 5 km or 1 km, dependent on applications. Thus, the corresponding domain is 100 km x 100 km or 20 km x 20 km, respectively.

The governing equations are solved numerically by a finite-differencing method at each grid point. In general, the so-called "leap-frog" method, centered time and space differences, is used for the calculation except for the Laplacian terms, in which the forward time differences must be used for computational stability (see Richtmyer and Morton, 1967).

More specifically, the equations being used have both linear and non-linear terms (eg, $g \nabla Z_s$ and $V_s . \nabla \theta_s$ in Equation (2-1)). If μ and ν are any two variables, linear space differences are computed by

$$\frac{\partial \mu}{\partial x} = \frac{\mu(x+\Delta) - \mu(x-\Delta)}{2\Delta} \ , \qquad (2\text{-}15)$$

where Δ is the grid spacing in both horizontal directions. Non-linear space differences are computed by

$$\nu \frac{\partial \mu}{\partial x} = \frac{1}{2}\left[\frac{\nu(x+\Delta)+\nu(x)}{2} \cdot \frac{\mu(x+\Delta)-\mu(x)}{\Delta} + \frac{\nu(x)+\nu(x-\Delta)}{2} \cdot \frac{\mu(x)-\mu(x-\Delta)}{\Delta}\right] . \qquad (2\text{-}16)$$

The Laplacian ($\nabla^2\vec{V}_s$ in Equation (2-1)), on the other hand, is calculated by

$$\nabla^2\mu = \frac{1}{2\Delta^2}[\mu(x+\Delta,y)+\mu(x-\Delta,y)+\mu(x,y+\Delta)+\mu(x,y-\Delta)-4\mu(x,y)]$$
$$+ \frac{1}{4\Delta^2}[\mu(x+\Delta,y+\Delta)+\mu(x+\Delta,y-\Delta)+\mu(x-\Delta,y+\Delta)+\mu(x-\Delta,y-\Delta) \qquad (2\text{-}17)$$
$$-4\mu(x,y)] .$$

In addition, the pressure gradient force term in Equation (2-1) is the average of the values at $(t+\Delta t)$ and $(t-\Delta t)$, where Δt is the time step. This is suggested by Kwizak and Robert (1971) to control gravity waves. However, the method used in the present model is explicit and not implicit, since $\ln P_s(t+\Delta t)$ is available from Equation (2-3) before Equation (2-1) is evaluated.

2.2.2 Initialization

To start the integration the model requires initial values of $\vec{V}_s$, T_s or θ_s, $\ln P_s$ as well as γ , a lapse rate of the free atmosphere. In the model, γ is determined from 850 and 700 mb data at a reference station. The initial surface winds are computed assuming a balance between pressure gradient, Coriolis and frictional forces. Such a balance of forces yields the following two equations for the initial winds

$$\sqrt{2}\, f\, V_g \sin\phi = F \qquad (2\text{-}18)$$

$$\sqrt{2}\, f\, V_g \cos\phi = \sqrt{2}\, f\, V + F , \qquad (2\text{-}19)$$

where ϕ is the angle between the surface geostrophic wind and the surface wind. These two equations are solved iteratively for the initial ϕ and V.

Also, assuming that the 850 mb is the reference pressure level of the layer of topographic influence and that the temperature lapse rate in this layer is initially the same as the free atmosphere lapse rate above, the initial surface temperature can then be obtained by

$$T_s = T_{85} + \gamma(Z_{85} - Z_s) , \qquad (2\text{-}20)$$

where T_{85} and Z_{85} are the temperature and height fields at the 850 mb level, respectively.

The initial horizontal pressure gradient force is given by

$$\frac{\partial}{\partial Z}(\alpha\nabla P) = (g\nabla Z_{85} - \alpha_o\nabla P_o)/Z_{85} , \qquad (2\text{-}21)$$

where α is the specific volume and the subscript o denotes mean-sea-level values. The initial surface pressure is computed from the hydrostatic equation

$$P_s = P_{85} \left[\frac{T_s}{T_{85}} \right]^{g/R\gamma} \qquad \text{for} \quad \gamma \neq 0 \qquad (2\text{-}22)$$

and

$$P_s = P_{85} \exp\left[\frac{g(Z_{85}-Z_s)}{RT_{85}} \right] \qquad \text{for} \quad \gamma = 0\,, \qquad (2\text{-}23)$$

where P_{85} = 850 mb. Note that the initial surface pressure is only dependent on height and temperature variations at the 850 mb level. Figure 1 displays a schematic picture of this initial structure of the model.

Thus, the meteorological input data for the model to begin an integration consist of the mean sea-level wind, temperature and pressure, the 850 mb and 700 mb heights and temperatures at a reference station. For a lakeshore environment, the reference station should be sufficiently far inland from a shoreline so that these input data are unaffected by the land-lake discontinuity. Having calculated the initial fields of $\vec{V}_s$, T_s and $\ln P_s$, the model is ready for integration.

2.2.3 Boundary Conditions

No upper and lower boundary conditions are required in the model since it is a one-layer, two-dimensional horizontal model. On the lateral boundaries the winds are held constant and the temperatures and pressures are set equal to their values, one grid distance inside the domain. This condition avoids large pressure gradients near the boundaries which would propagate inward.

Furthermore, the domain size used in the present study is assumed to be large enough to cover the circulation generated by local topographical features and diabatic forcing. However, if in some cases sudden changes in wind speed and direction near the boundaries are produced, the size of the study domain would have to increase to ensure the predictions having the least effect from the boundaries.

3.0 MODEL MODIFICATION

3.1 Model Structure

The original model consists of one main program and thirteen subprograms (see Tam, 1984). The main program provides values for

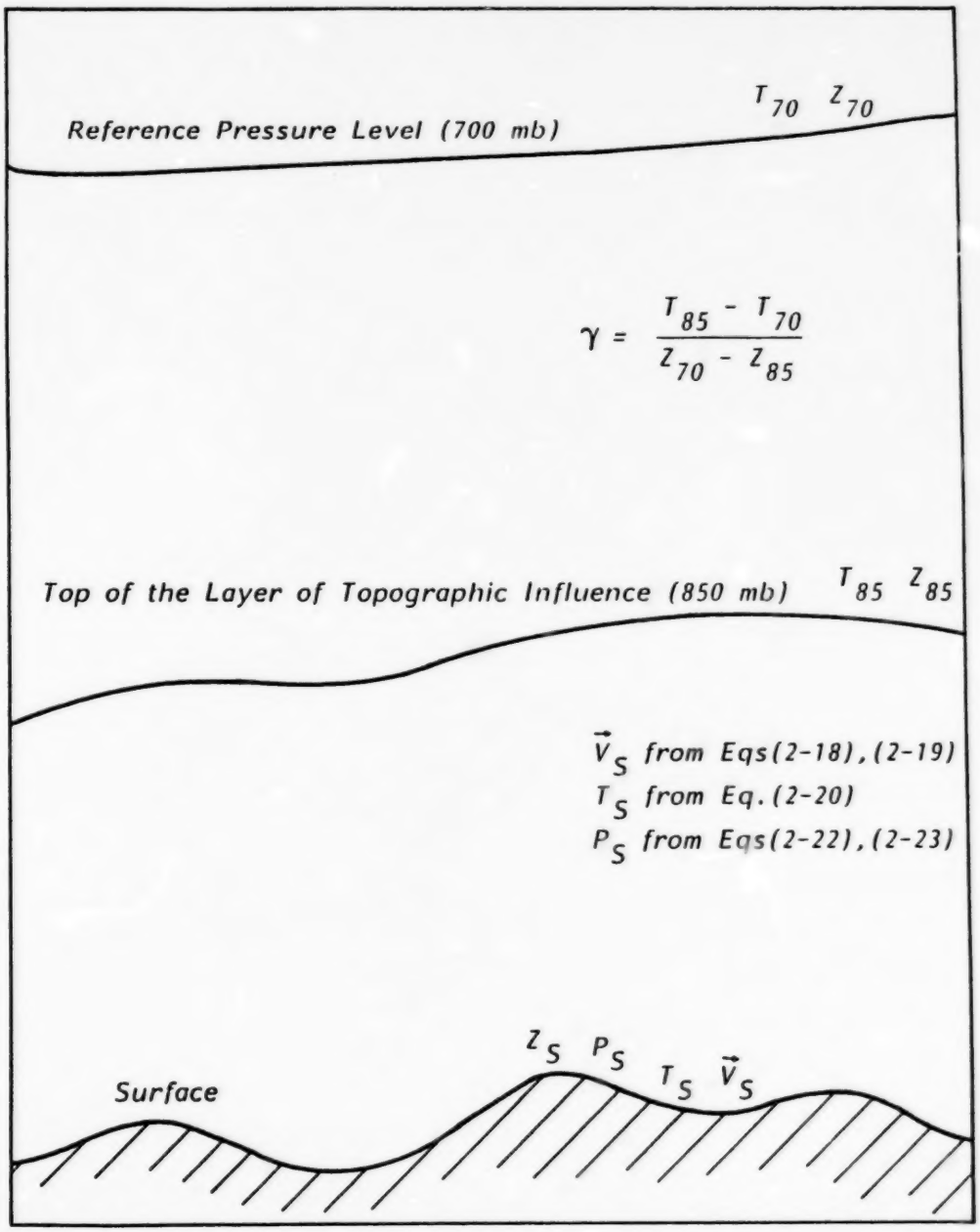

FIGURE 1

A SCHEMATIC PICTURE OF THE INITIAL STRUCTURE OF THE MODEL

constants and controls the execution of all the subprograms which perform individual calculation loops. This structure requires a large storage space and relatively long execution time during the calculation. To optimize this drawback, a so-called "segment programming" was developed in the present study. The main program was divided into several segment programs. Each of the segment programs performs executions only needed at the time and only once. Thus, the segment program does not need to store after it has been executed. As a result, the computer requirement could be reduced considerably.

In the present model, the main program provides values of constants; sets up the study domain, grid size, the starting time and termination time of the prediction and then schedules the first segment program. The first segment program reads in basic physical input data which will not change in the calculation from one case study to another. The second segment program reads in basic meteorological input data specific to the case being studied and performs the initialization of surface temperature, pressure and wind fields.

The third segment program performs commands to calculate surface temperature, pressure and wind fields by adding the local topographical and thermal effects. After a case study has been calculated, this segment program will perform commands to print or plot the output results and attempt to read in another set of input meteorological data for the next case study. If there is no other set of input data, the program will simply terminate.

3.2 Input Data

The input data needed to begin the integration consists of physical data and meteorological data. The former may also be considered as fixed data since they will not change from one case study to another. These data are

STNID	Station identification up to 16 characters
LATT	Latitude of the reference station
LONN	Longitude of the reference station
ZREF	Terrain height (m) of the reference station
XREF	X-coordinate of the reference station
YREF	Y-coordinate of the reference station
DELL	Horizontal grid spacing (m)
ZS	Terrain heights (m) of each grid point in the study domain
WW	Water fraction of each grid point in the study domain
TWATER	Water temperature (^{o}C)

Note that the grid network of the present model is fixed to be 20 x 20 grid points. Separate files of the physical input data have been created for the applications to the Lakeview, Pickering and Nanticoke regions.

On the other hand, the meteorological data are those representing the synoptic-scale conditions. They vary from one case study to another. These data include

T70	700 mb temperature (^{o}C)
Z70	700 mb height (m)
T85	850 mb temperature (^{o}C)
Z85	850 mb height (m)
DELZ85	850 mb contour gradient (m)
DELS85	850 mb contour spacing (^{o} lat)
DZ85A	850 mb contour angle
TREF	Surface temperature (^{o}C) at the reference station
P	Surface pressure (mb) at the reference station
DELP	Surface pressure gradient (mb) at the reference station
DELS	Surface isobar spacing (^{o} lat)
DPA	Surface isobar angle

For a large area, it is desirable to have meteorological data from a number of stations so that the synoptic-scale weather pattern can be well defined. However, for a domain of 100 km x 100 km, as used here, the area is sufficiently small that it may be justifiable to use only one set of synoptic scale input data. These data are obtained from the CMC grid data available in Meteorology Section's weather data base (see Schaedlich, 1984).

3.3 Model Efficiency

With the above optimization and on 20 x 20 grid points, the model requires approximately 30 seconds on the HP1000 system at the Meteorology Section for initialization and integration of the surface wind and temperature fields for each hour forecasting. Run time may be longer if graphics are required. Run time may also be reduced if the size of the study domain and/or the resolution of the grid decrease.

With the above modifications, the model can also accommodate the weather pattern changes, since the input synoptic weather data can be updated constantly.

4.0 EXPERIMENTAL RESULTS

4.1 Physical Input Data

The case presented here is February 6, 1986 over the Lakeview region which is located at the west end of Lake Ontario. As shown in Figure 2, the main physical features of this region include an urban area (Metropolitan Toronto) and a large body of water (Lake Ontario). There are also river ravines across the area (eg, Credit River and Don River), and high lands to the northwest. The Pearson International and Toronto Island Airport are within the

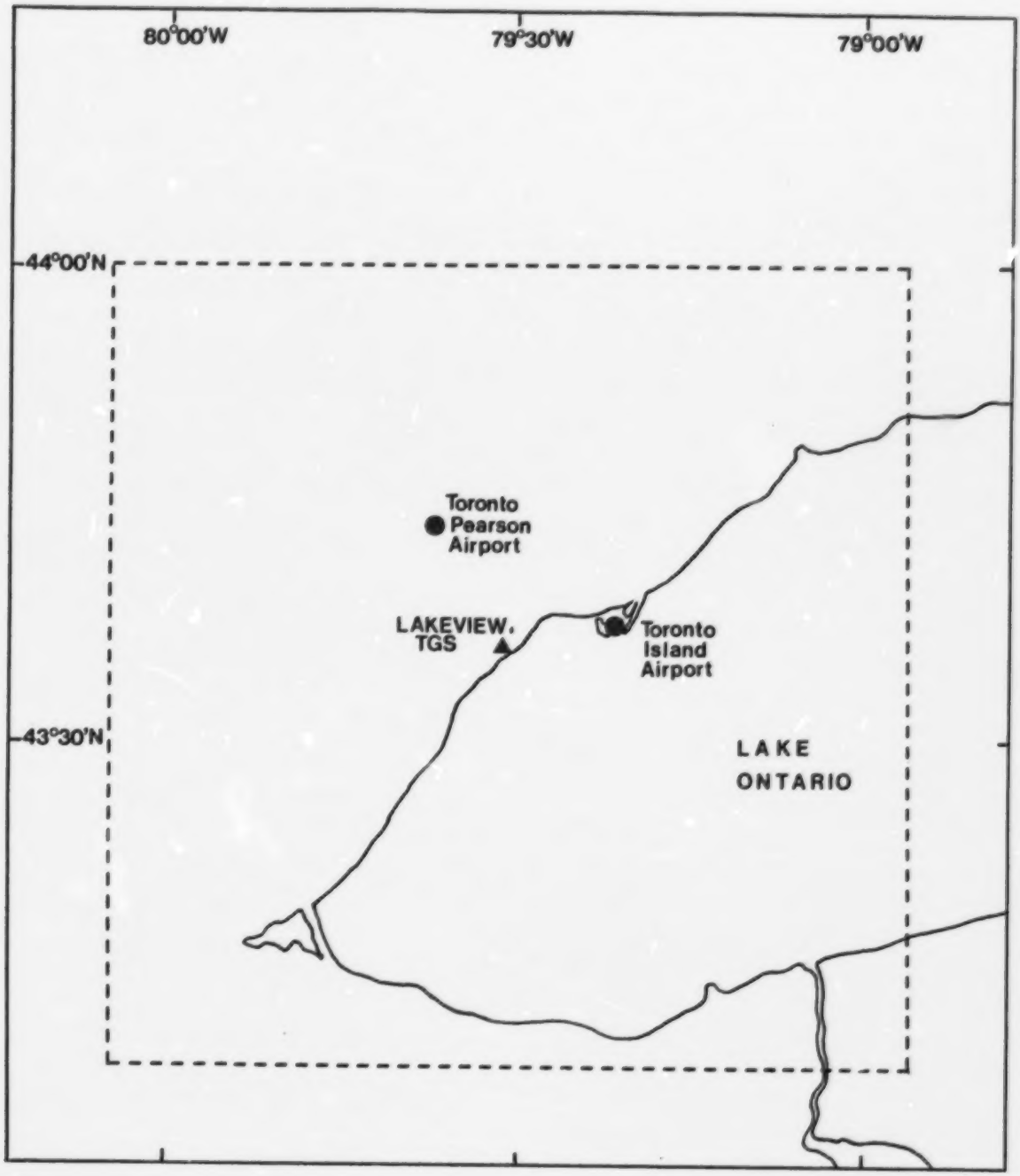

FIGURE 2

THE LOCATION OF THE LAKEVIEW STUDY REGION

region. The former was selected as the reference station which provides the required meteorological input data. The geographical coordinates of Pearson International Airport are 43°41'N latitude and 79°38'W longitude.

This study region was divided into 20 x 20 grid points with a 5-km grid size. Figure 3 displays the terrain heights at each grid point. It can be seen that the terrain height increases gradually from 76 m above mean-sea-level at the shoreline to over 400 m at about 55 km inland from the lake. The terrain height of Pearson International Airport (at grid point (9,13)) is 180 m.

The water temperatures across the lake were obtained from the mean value based on the 30-year period of record and were assumed constant for the month of the study period. They are given in Table I.

TABLE I

THE WATER TEMPERATURES USED IN THE PRESENT SIMULATIONS

Mth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Temp (°C)	0	0	0	1	3	5	10	10	8	6	3	1

4.2 Meteorological Input Data

The surface synoptic weather pattern on February 6, 1986 was dominated by a high pressure system centered over the northern Ontario and western Quebec area and a low pressure system located over Newfoundland with a cold front extending southwestward through the US New England to the Great Lakes (see Figure 4). These two systems produced a northerly to northeasterly synoptic-scale flow over the southern Ontario region.

The 850 mb weather map (Figure 5) confirmed the weather patterns shown on the surface map except that the positions of the cold front were slightly to the north. This shift of position indicates warm air at this level above the ground.

The thermal structure of the lower atmosphere on this day may be revealed from the upper air sounding at Buffalo, New York. Table II displays the sounding at 1200 Z, February 6, 1986. A super-adiabatic layer topped by an inversion is noted at lower levels. This inversion is based at about 840 mb level and topped at 700 mb. Above that the temperature decreases rapidly with height indicating a very cold advection aloft. The free atmosphere lapse rate derived from the 700 and 850 mb data is 1.9°C/km.

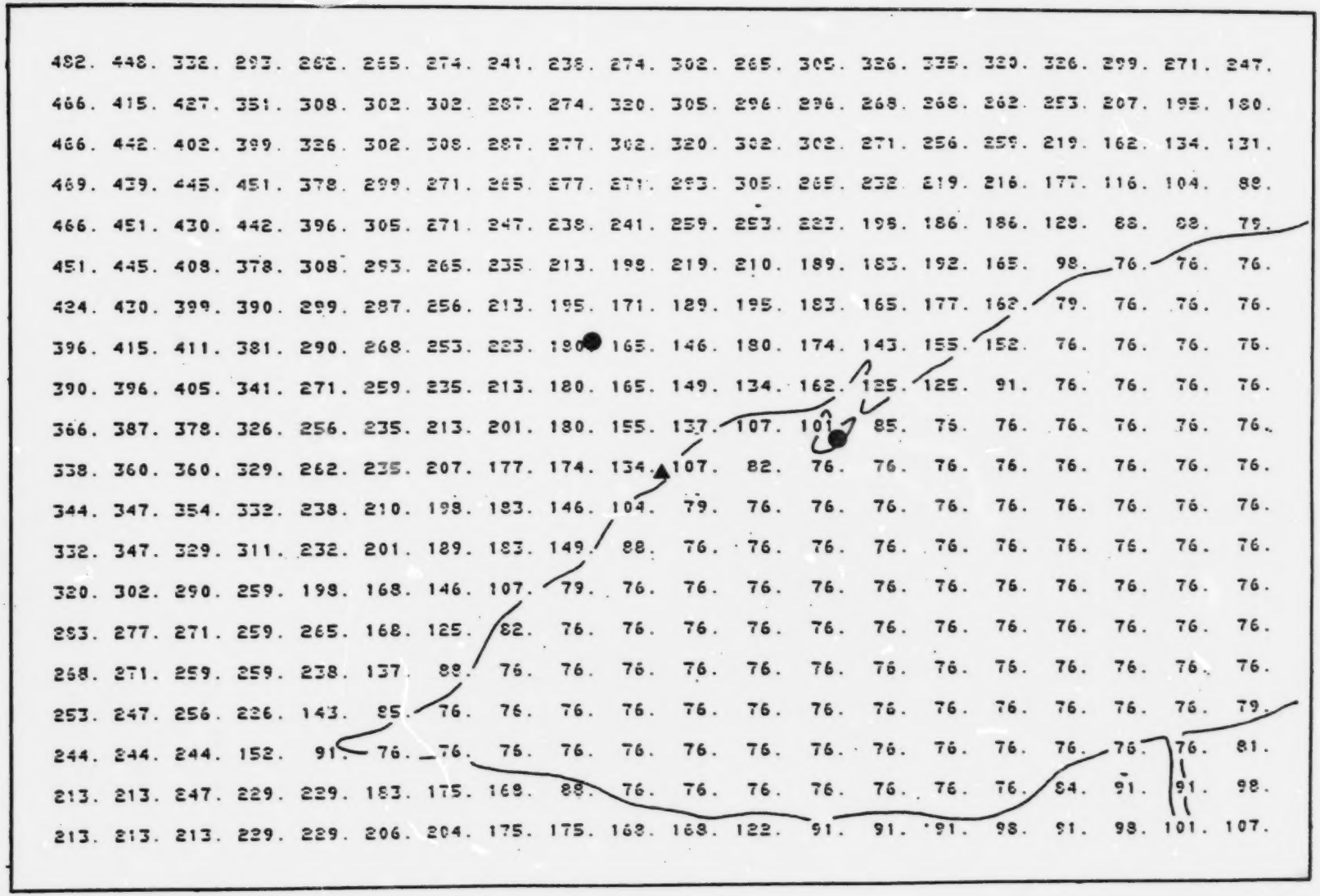

FIGURE 3

THE TERRAIN HEIGHTS (m) OF THE LAKEVIEW STUDY REGION

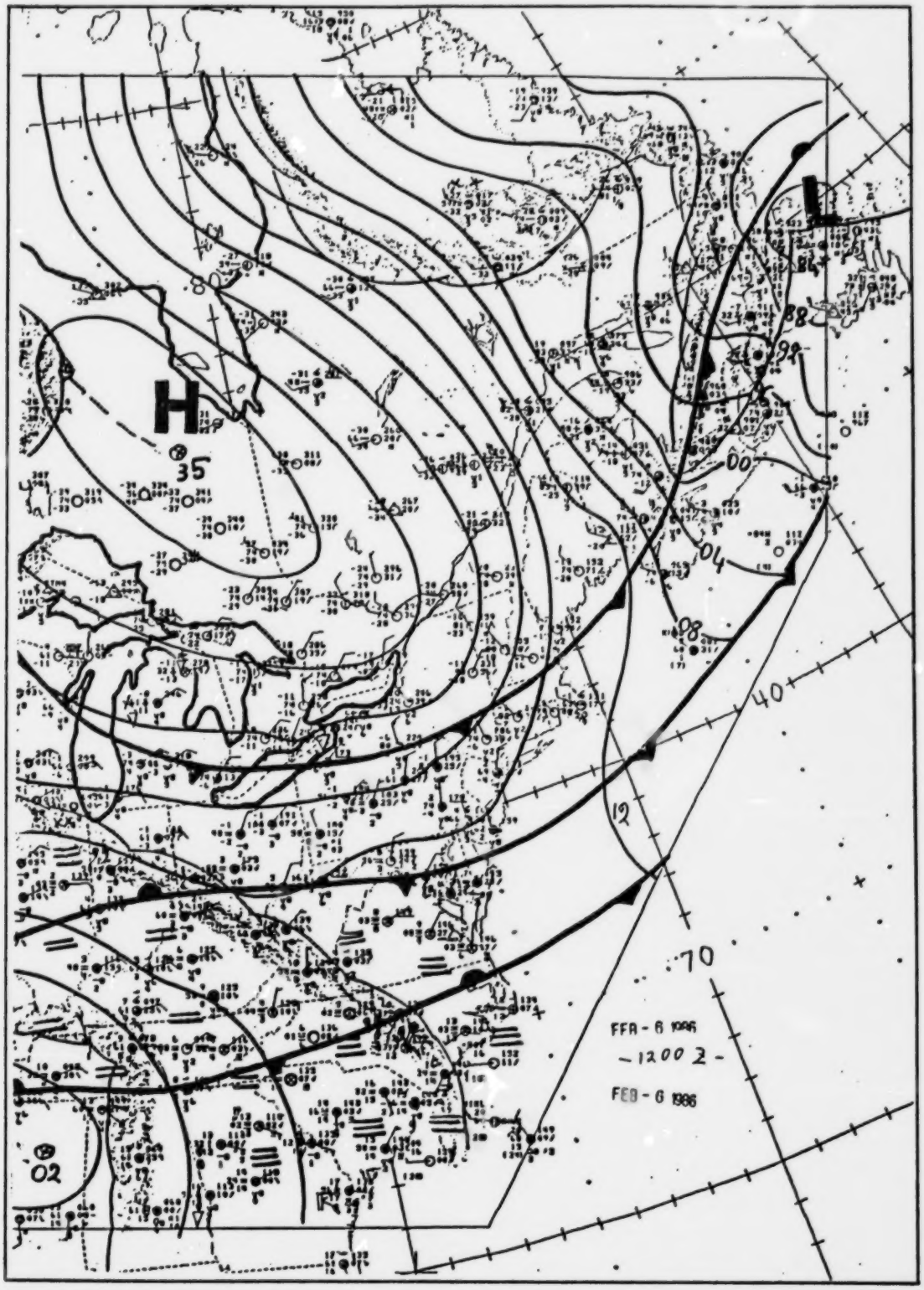

FIGURE 4

THE SURFACE SYNOPTIC WEATHER MAP AT 1200Z ON FEBRUARY 6, 1986

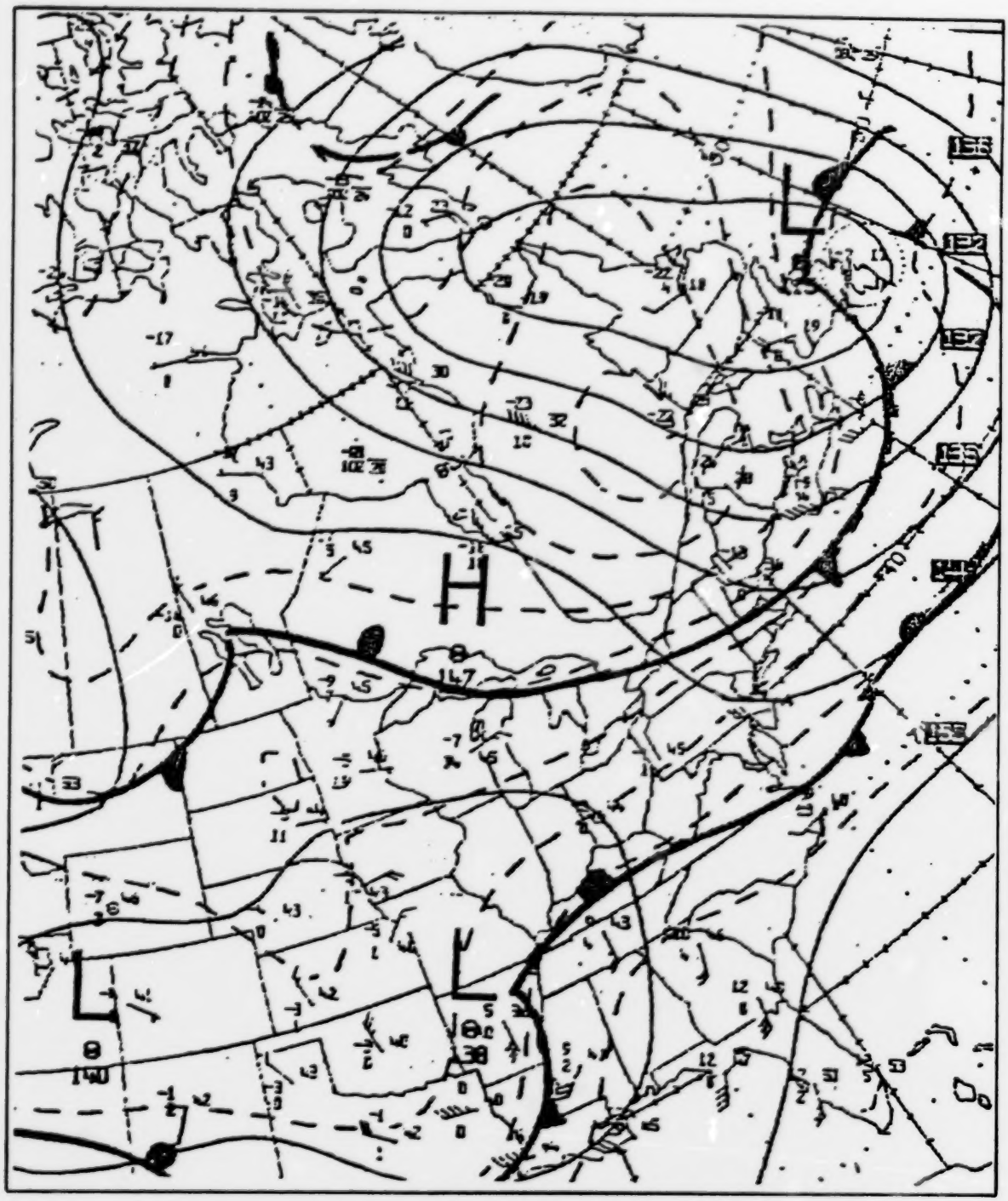

FIGURE 5

THE 850 mb SYNOPTIC WEATHER MAP AT 1318Z ON FEBRUARY 6, 1986

TABLE II

UPPER AIR SOUNDING AT 1200 Z, FEBRUARY 6, 1986 AT BUFFALO, NEW YORK

Pressure (mb)	Elevation (m)	Temp (°C)	Dew Point Depression	Wind Direction	Wind Speed (km/h)
1000	183				
996	0	- 4.5	4.6	60	16
994		- 4.7	7.0		
949		- 8.9	1.6		
897		- 9.3	0.2		
850	1,443	-11.7	0.3	15	14
839		-12.3	0.3		
832		-10.3	1.2		
830		- 9.9	4.1		
814		- 9.1	12.0		
776		- 6.1	16.0		
729		- 6.7	17.0		
700	2,952	- 8.9	16.0	300	29
500	5,480	-25.5	14.0	280	47
465		-29.7	4.8		
400	7,060	-36.5	14.0	275	71
386		-38.9	14.0		
331		-47.3			
300	8,990	-49.7		280	98
284	9,284	-50.9		275	106
267		-44.1			
250	10,190	-46.1		275	107
242		-47.1			
200	11,680	-45.9		260	107
277		-44.1			
150	13,590	-49.7		270	118
133		-55.3			
200	16,170	-60.7		270	69

Table III lists the meteorological input data required to simulate this study case. Again, these data were obtained from the CMC real-time upper air data base, the FG data message.

4.3 Model Simulations

The surface wind and temperature fields on February 6, 1986 were simulated for 12 hours consecutively from 1300 Z to 2400 Z. During this 12-hour period, the model simulated winds veer from north-northeast to east-northeast and double the wind speed from 5 km/h to 11 km/h. The model simulated temperatures also increase gradually.

TABLE III

THE METEOROLOGICAL DATA USED FOR THE SIMULATION OF FEBRUARY 6, 1986

hr	T70 (C)	Z70 (m)	T85 (C)	Z85 (m)	DELZ85 (m)	DELS85 (lat)	DZ85A	TREF (C)	P (mb)	DELP (mb)	DELS (lat)	DPA
13	-11.3	2948.7	-7.7	1436.4	60.0	13.2	312.5	-14.3	1024.6	4.0	2.6	88.4
14	-11.3	2949.3	-7.8	1437.2	60.0	15.1	309.9	-13.7	1024.6	4.0	2.5	91.4
15	-11.3	2949.8	-7.9	1437.9	60.0	17.6	306.6	-13.2	1024.7	4.0	2.5	94.3
16	-11.4	2950.4	-7.9	1438.7	60.0	20.9	301.9	-12.7	1024.7	4.0	2.5	97.2
17	-11.4	2951.0	-8.1	1439.5	60.0	25.5	295.1	-12.2	1024.7	4.0	2.4	99.9
18	-11.4	2951.6	-8.2	1440.2	60.0	31.9	284.6	-11.7	1024.8	4.0	2.4	102.6
19	-11.4	2952.2	-8.2	1440.9	60.0	39.6	268.2	-11.2	1024.8	4.0	2.3	105.1
20	-11.5	2952.8	-8.3	1441.7	60.0	45.0	244.7	-10.6	1024.8	4.0	2.3	107.6
21	-11.5	2953.4	-8.4	1442.5	60.0	42.7	219.5	-10.1	1024.9	4.0	2.2	109.8
22	-11.5	2954.0	-8.5	1443.2	60.0	34.9	200.1	-9.6	1024.9	4.0	2.2	112.0
23	-11.5	2951.6	-8.5	1441.0	60.0	32.4	188.9	-9.7	1024.6	4.0	2.1	112.4
24	-11.5	2949.3	-8.4	1438.8	60.0	29.3	179.7	-9.7	1024.3	4.0	2.1	112.7
1	-11.5	2947.0	-8.4	1436.6	60.0	26.2	172.1	-9.8	1024.0	4.0	2.0	113.1

Table IV lists the model simulated and the predicted surface wind and temperature fields by the CMC Spectral model at Pearson International Airport. In general, the model simulated winds agree quantitatively with the CMC-predicted values. Both the veering wind direction and increasing wind speed are produced in both results. On the other hand, there are differences between the magnitude of the model simulated and the CMC-predicted surface temperatures. However, rapid warming at the surface was predicted by the model.

TABLE IV

COMPARISON OF THE MODEL SIMULATED AND CMC-PREDICTED SURFACE WINDS AND TEMPERATURES AT PEARSON INTERNATIONAL AIRPORT

Hour (GMT)	13	14	15	16	17	18	19	20	21	22	23	24
Simulated Wind Speed (km/h)	14	14	14	15	15	16	16	16	16	16	16	16
Simulated Wind Direction (from)	35	39	43	47	50	55	60	64	68	71	75	78
Simulated Temperature (^{o}C)	-19	-19	-18	-18	-17	-16	-16	-15	-15	-14	-13	-13
CMC Predicted Wind Speed (km/h)			13			13			14			15
CMC Predicted Wind Direction (from)			46			57			61			69
CMC Predicted Temperature (^{o}C)			-11			-6			-5			-8

5.0 DISCUSSION AND CONCLUSIONS

A relatively simple, one-level, sigma coordinate model that can be used to diagnose the surface winds and temperatures is described in this report. The model calculates winds and temperatures using horizontal momentum and temperature tendency equations at the surface level ($\sigma = 1$ in sigma coordinates) and includes terrain effects, surface friction and diabatic heating or cooling.

Basically, the governing equations are solved numerically by a finite-differencing method. In the present study, the model was constructed using a "segment programming" in order to reduce the computer requirement. The model consists of one main program and three segment programs, each only performs executions needed at the time and only once.

The model was also designed to accept real-time, upper air data available from CMC as input meteorological information. This has an advantage that the model can accommodate the weather pattern changes, since the input synoptic weather data can be updated from CMC constantly.

Preliminary applications of the model indicated that the simulated winds agree quantitatively with the CMC-predicted values. For the case presented in this report, both the veering wind direction and increasing wind speed were produced correctly by the model. On the other hand, there are differences between the magnitude of the model simulated and the CMC-predicted surface temperatures. This may be attributed to the approach the model used to calculate surface diabatic heating or cooling rates.

In the model, the effect of low-level diabatic heating or cooling is parameterized by

$$Q = \frac{\theta}{T} \frac{(T_f - T_i)}{\tau} \qquad (5\text{-}1)$$

(for definition, see Section 2.1). As noted, the heating or cooling rate starts with a fictitious temperature which is determined by linear extrapolation downward from 700 and 850 mb. This approach is considered to be adequate when the atmosphere is stably stratified. However, when there is an inversion or sudden change of temperature aloft, the fictitious temperature may show an oscillating nature and concurrently, produce an unreasonable heating or cooling rate at the surface. As a result, the surface temperature may be either overestimated or underestimated.

One way to improve the surface temperature calculation is to determine the initial surface temperature by solving a heat balance equation. The general expression of a heat balance equation at the surface may be written

$$Q_S + Q_{LD} - Q_{LU} - Q_H - Q_E - Q_A = 0, \qquad (5\text{-}2)$$

where Q_S is the solar radiation, Q_{LD} is the downward longwave radiation, Q_{LU} is the upward longwave radiation, Q_H is the sensible heat flux, Q_E is the latent heat flux and Q_A is the heat flux through the soil layer. Since the longwave radiation varies with the fourth power of the surface temperature due to the Stefan-Boltzmann law and the sensible and latent heat fluxes are dependent on surface winds, Equation (5-2) is not linear and is difficult to solve analytically. However, it is possible to solve numerically by using an iteration procedure by linking Equation (5-2) with the surface wind equation. Further work is required in this area.

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APPENDIX

THE USER'S GUIDE TO THE DIAGNOSTIC WIND FIELD MODEL

A.1 MODEL STRUCTURE

The model consists of one main program, three segment programs and 8 subprograms. The main program specifies values of constants and sets up the study domain and the starting time of the simulation. The study domain is rectangular in shape and divided into a grid network. The origin of the grid network is designated at the lower left corner of the domain. Julian time is used to specify the simulation. Then the first segment program is called.

The first segment program, CRTE1, reads in basic physical input data needed by the model to represent the surface features of the study domain. The data include the name and location (latitude and longitude) of the reference station at which meteorological input data are available; terrain heights and water fraction of each grid point in the study domain; and the horizontal grid spacing. These data are given in subroutine READC. The water temperatures are read by calling subroutine WATMP.

The second segment program, CRTE2, is then called to read in basic meteorological input data specific to the case being studied. The meteorological data are given in subroutine READ4 and include temperature, pressure, pressure gradient and isobar angle and spacing at the surface; temperatures and heights at 850 mb and 700 mb and the contour gradient, angle and spacing at 850 mb at the reference station. After these meteorological data are read, CRTE2 then performs the initialization of surface temperature, pressure and wind fields by calling subroutines ITEMP, IWIND and INIT.

Finally, the third segment program, CRTE3, is entered to calculate surface temperature, pressure and wind fields by adding the local topographical and thermal effects. The calculations are performed by subroutines PROGP, PROGV and TRAN. Results are printed as frequently as desired.

After a case study has been calculated, CRTE3 will attempt to read in another set of meteorological input data for the next case study. If there is no other set of input data, the program will simply terminate. A flow chart of the algorithm is given in Figure A-1.

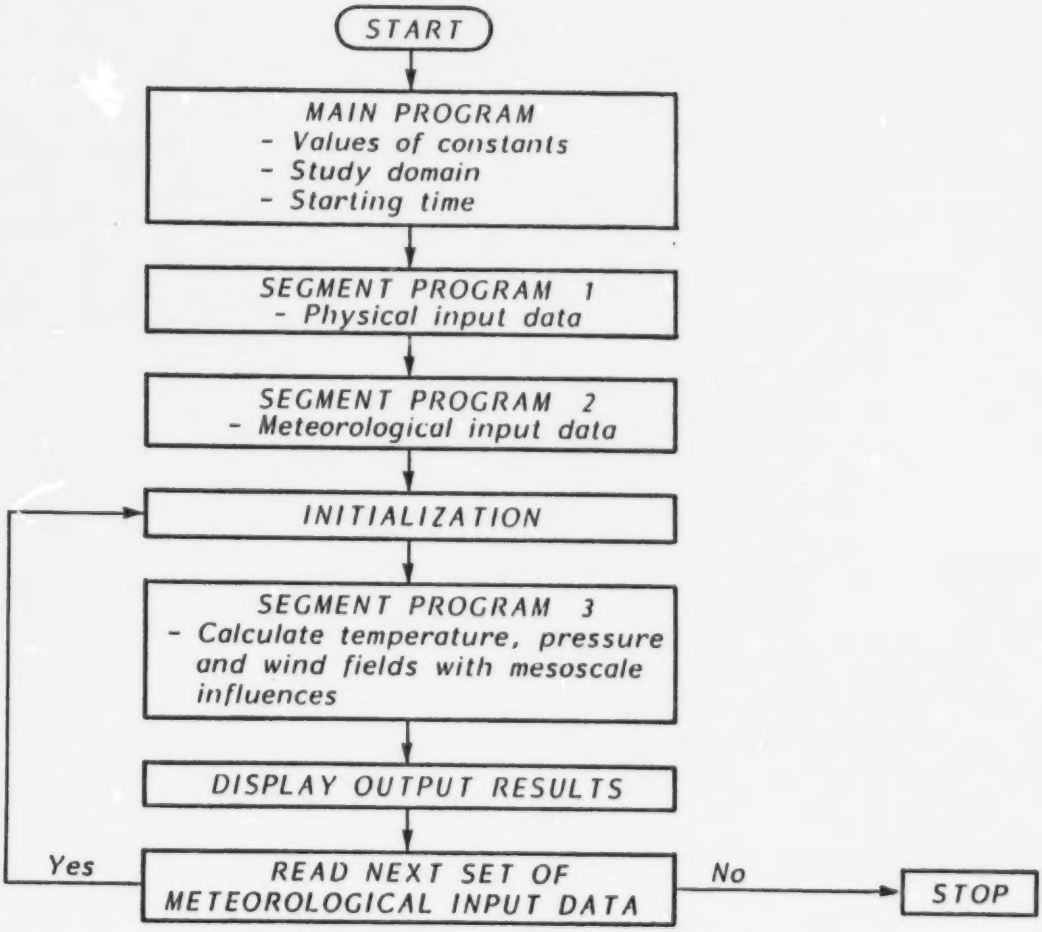

FIGURE A-1

THE FLOW CHART OF SURFACE WIND AND TEMPERATURE CALCULATION

A.2 MAJOR VARIABLES IN THE MODEL

ARRAY	space for common variables
ARRAY1	space for common variables
ARRAY2	space for common variables
C	drag coefficient
DELL	horizontal grid size
DELT	time interval
DELZ	vertical grid size
DUMMY	space for common variables
F	Coriolis parameter
G	acceleration due to gravity
H	depth of the model
HL	boundary layer height over land
HW	boundary layer height over water
I	index for y-coordinate
J	index for x-coordinate
KM	momentum eddy diffusivity
KT	thermal eddy diffusivity
LNPS	natural logarithms of surface pressure
LPOLD	natural logarithms of surface pressure at the previous time step
LPNEW	natural logarithms of surface pressure at the new time step
OMEGA	angular velocity of earth
PI	
PINIT	surface pressure at the initial time
PO	reference surface pressure (1000 mb)
PS	surface pressure
P85	850 mb
R	gas constant
RAD	radian

THETAS	surface potential temperature
THINIT	surface potential temperature at the initial time
THNEW	surface potential temperature at the new time step
THOLD	surface potential temperature at the previous time step
TLDROP	heating or cooling rate over land
TMDROP	heating or cooling rate over water
TNEW	surface temperature at the new time step
TOLD	surface temperature at the previous time step
TS	surface temperature
TWATR	surface temperature over water
U	u-component
UNEW	u-component at the new time step
UOLD	u-component at the previous time step
V	v-component
VNEW	v-component at the new time step
VOLD	v-component at the previous time step
WW	water fraction
X	E-W coordinate
Y	S-N coordinate
ZS	surface terrain height